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Sulfur in Relation to Soil Fertility

By

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BOARD OF REGENTS OF THE OREGON AGRICULTURAL COLLEGE AND EXPERIMENT STATION

STATION STAFF

* Deceased, November, 1923.

CONTENTS

SUMMARY

The experiments herein reported, covering the progress of sulfur investigations with Oregon soils, are maintained by the Soils department of the Oregon Agricultural College Experiment Station as a phase of Oregon Soil and Soil Water Investigations provided for in Ch. 340, Session Laws of 1919 and its continuations. Earlier studies along this line were reported in Oregon Station Bulletins 163 and 167, now out of print. The present bulletin is prepared to meet the heavy demand for information on the subject of sulfur in relation to soil fertility. Most of the quantitative analyses were made by the department of Agricultural Chemistry and bacterial studies were made by the department of Bacteriology.

1. In 1912 the Oregon Experiment Station found that increases in alfalfa yields equivalent to those obtained by use of potassium sulfate in Eastern Oregon experiments by W. L. Powers and by use of acid phosphate in Southern Oregon experiments by F. C. Reimer could be obtained by use of elemental sulfur.

2. Subsequent analyses of soils and crops indicated, and field, greenhouse, and laboratory experiments seem to confirm the view that sulfur is a limiting element, and that the increase caused by its application was not to any great extent due to indirect action.

3. Similar tests of the leading two dozen arid and semi-arid soil types of Oregon proved that there are at least 100,000 acres of alfalfa that can be increased one ton or more an acre each year with sulfur at a cost not exceeding one dollar a ton for the sulfur applied.

4. Legumes, particularly alfalfa, red and alsike clover, have given marked response to sulfur fertilizers. Moderate increases have been obtained on wheat and potatoes, and but little increase from this treatment where field peas, beans, corn, kale, rape, or sunflowers were grown. The benefit with potatoes is attributed largely to indirect action in controlling potato scab and some increase in ammonification.

5. H. V. Tartar and H. G. Miller of the Oregon Experiment Station found that sulfur increases protein content of crops.

6. Numerous recent analyses and four fertility field experiments show that the extensive red hill regions extending from Coos Bay to Astoria and from the Pacific to the Cascades, covering the Coast hills and the hills surrounding the Willamette Valley, contain only 150 to 400 pounds of sulfur in the plowed surface of an acre, and yield 25 to 50 percent increase of clover when sulfured. The same is true regarding grain from sulfur applications.

7. Sixty years of cropping has depleted this initial supply in representative soil types from 300 pounds to 200 pounds an acre, and the indication is that available sulfur is deficient at the close of the rainy season.

8. Lysimeter studies show that 40 to 45 pounds of sulfur is lost in the annual percolate, while only 3 to 6 pounds an acre a year is received in the annual precipitation.

9. Laboratory experiments strongly indicate that a little gypsum or sulfur and lime aids nitrification at the beginning of the growing season, there being practically no nitrates in Western Oregon soils at that time because of low temperature and excessive moisture. After the cold, wet weather has depleted the nitrate and sulfate supply in Western Oregon, the sulfur or calcium sulfate (gypsum) aids in establishing a stand of new clover. Sulfur seems to be related to nitrogen supply.

10. Sulfofication* studies by Professor Halversen of the Bacteriology department show that most of the Oregon soil types contain organisms capable of oxidizing sulfur more rapidly than is necessary for plant needs. Sulfur applied to field plots has caused visible results in two weeks. Elemental sulfur is the most economical form. It should be applied early and harrowed in to insure results the first season.

11. Water culture, and pot culture and tank experiments strongly indicate that sulfur is an especially critical element, but that only a small amount is necessary. Yields have been markedly increased and water requirements strikingly decreased by adding a little sulfur against its elimination or near elimination.

12. From a study of the literature and inquiry of experiment stations throughout the United States, it seems that the basaltic region of the Northwest is the greatest field for the profitable use of sulfur. Basalt contains only limited amounts of sulfur. Soils receiving large quantities of sulfate bearing irrigation water, those high in organic matter, and those containing sulfate alkalies in the Great Basin region are plentifully supplied with sulfur; while soils in eastern and southern states receive a fair supply of sulfur in fertilizers, manures, and from precipitation in the heavy coal-consuming sections.

13. Thorough field experiments with sulfur as a fertilizer in Oregon, now of ten years' duration, are believed to be the most extensive to be found. Applications amounting to 1,000 pounds of sulfur an acre during this period have resulted in continued marked increase in yield. The duration of the increase in yields from a hundred-pound application on an acre of soil is three to five years, the heavier soil types retaining sulfur longer. Maintenance of one element will not make a permanent system of agriculture.

14. Use of elemental sulfur beyond the amount needed to meet the absolute deficiency has tended to aggravate soil acidity in humid and semi-humid sections, as judged by Truog acidity tests of Southern and Western Oregon soils made by the Soils department and hydrogen-ion tests made of samples submitted to the department of Bacteriology.

15. It appears that sulfur may be used on red hill soil at one-third the cost of sulfur secured in gypsum, the use of which is common in Western Oregon. Its continued use will make occasional liming more necessary. A combination of sulfur, rock phosphate, manure, and lime has given maximum yields in some recent field experiments.

* Sulfur oxidation.

Sulfur in Relation to Soil Fertility

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INTRODUCTION

Until recent years investigators have generally agreed that the chemical elements in which soils are most often deficient are potassium, nitrogen, and phosphorus. To supply these elements a great fertilizer industry has been built up. In addition calcium is often needed in carbonate form to correct soil acidity. The older systematic fertilizer experiments have been worked out on this basis.

Although sulfur has long been regarded as essential to plant growth, the small amount formerly found in plant ash did not indicate that it was likely to be a critical or limiting element in crop production. During recent years, however, an improved fusion method of analysis has shown that such plants as alfalfa and the cabbage family show much more sulfur than early analyses indicated. A five-ton crop of alfalfa removes about twenty-five pounds of sulfur from one acre, whereas only twenty-five pounds or less of phosphorus would be contained in five tons of alfalfa. On the new basis rape has been found to contain twenty pounds of sulfur in a ton; and a fifty-bushel oat crop, including straw, would remove about sixteen pounds of sulfur.

The use of sulfur as a fertilizer began as early as 1913 in Oregon, and systematic field and laboratory experiments which have extended over a period of years give perhaps the most marked increases in yields that have been secured by investigators of sulfur in relation to soil. Since previous reports of sulfur experiments in Oregon are out of print and many new facts have been developed, a statement of the progress of these studies is here given to meet the large demand for information on this subject.

This bulletin is issued as a feature of Oregon Soil and Soil Water Investigations as provided for by the state legislature, Chapter 340, Session Laws 1919 and its continuations, 1921 and 1923.

Acknowledgement. The author here wishes to acknowledge the careful assistance of field agents W. W. Johnston, John Tuck, K. S. Taylor; laboratory determinations by Professor J. S. Jones and associates in the Experiment Station chemical laboratory; and suggestions and tests by Professor W. V. Halversen of the Bacteriology department. Helpful suggestions have been received from Director J. T. Jardine, Professors C. V. Ruzek and F. C. Reimer. Professor Reimer furnished data for experiments in Southern Oregon prior to 1918. The cooperation of branch experiment station superintendents and county agents has made possible a more extensive and correlated study than otherwise would have been possible.

Historical: Investigations in other states. A thorough review of literature dealing with sulfur as a plant food[1] has recently been issued, and space here permits mention of only essential facts developed. The value

of sulfur was recognized in France and Germany during the last half of the eighteenth century. Calcium sulfate was probably first used in America by Benjamin Franklin on his farm near Philadelphia. Hart and Peterson of the Wisconsin Experiment Station, using new methods of analysis found[2] the sulfur removed by average crop cereals to be about two-thirds of the phosphorus removed by these crops, while alfalfa required more sulfur than phosphorus. One hundred average crops of barley would require as much sulfur as is contained in the surface eight-inches of an average soil. Crops such as cabbage and turnips removed two or three times as much sulfur as phosphorus. It was also found that this soil farmed fifty to sixty years lost on the average 40 percent of the original sulfur content as compared with virgin soil. They calculated that the amount of sulfur lost in drainage water would exceed the amount brought in by the atmosphere and rain.

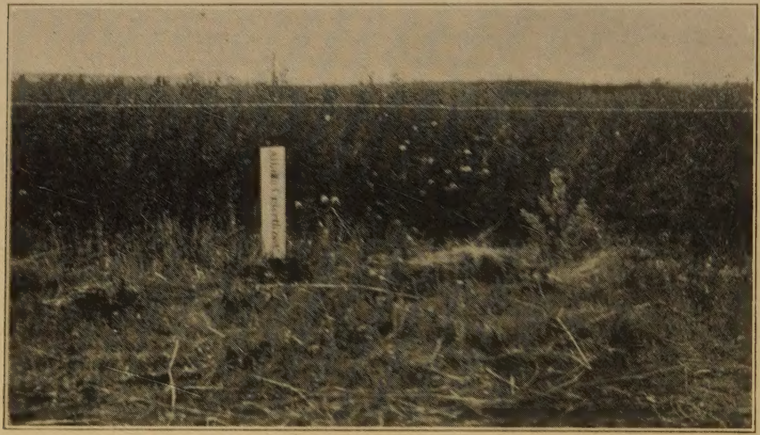

Fig. 1. Original sulfate plots, Redmond, 1912, untreated.

These facts led to renewed interest in sulfur content of soils. A thorough study of the sulfur content of Kentucky soil areas, made by Shedd,[3] shows that soils of that state usually contain less sulfur than phosphorus and that many staple crops respond to treatment with sulfur and sulfate. For years people have often applied sulfur to soil unknowingly in manure, potassium sulfate, ammonium sulfate, acid phosphate, and calcium sulfate.

It has been found that amounts of sulfur ranging from three to fifty pounds per acre each year, are added by rainfall, while the amount in drainage water has frequently been much larger.

A study of twenty years' fertilizer trials of the Ohio Experiment Station[4] shows the average yield of plants treated with acid phosphate, potassium sulfate, or ammonium sulfate to be higher than those treated with fertilizers containing no sulfur. In Illinois experiments potassium sulfate has not materially increased yields on normal soils.[5] Thirty-five years' use of gypsum at the Pennsylvania Experiment Station and eighteen years' use at the Ohio Experiment Station have not materially increased average yields. Various effects of sulfur have been noted.

Sulfur is used by the plant in the sulfate state, and Dr. P. E. Brown of the Iowa Experiment Station has shown that different groups of bacteria are associated with the oxidation of sulfur into available form.[6] Inoculation studies to hasten oxidation, or sulfofication, have been made at the New Jersey Experiment Station by Lipman.[7] At that station and others sulfur has been composted with raw rock phosphate to make available phosphate and with fair success. Increased activity of nitrifying bacteria due to sulfur and lime has been reported by different investigators. Greater root and nodule development has been noted and a higher protein content in crops secured. Some field and laboratory studies have been made with sulfur in the state of Washington,[1] and increases have been obtained in the yields of alfalfa from gypsum applications. Results have been less striking than those obtained in Oregon. Increases in yields have also been noted from studies in Utah, Montana, Idaho, and California. In the last named state the effects of sulfur, sulfuric acid, and sulfate have been considered in connection with the correction of alkali.[8]

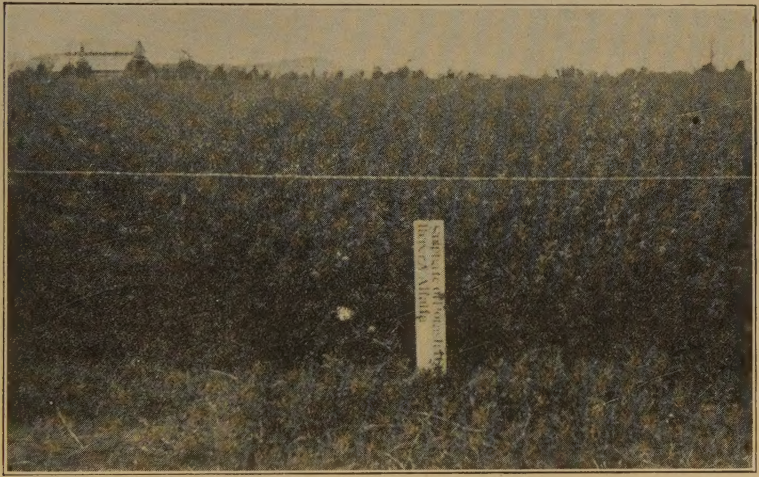

Fig. 2. With sulfur. Redmond, 1912.

Sulfur has been regarded as a stimulant by some,[9] and heavy applications have been made in France for that purpose. Use of sulfur has resulted in increased solubility of phosphorus and potassium compounds in soils. Sulfur was noted by McCool to hasten decay of organic matter.[10] The tendency of heavy applications to increase acidity has been variously reported. Indirect effects attributed to sulfur by various investigators include control of potato scab fungus[11] through increase in hydrogen-ion concentration and repelling of wireworms and other insects.

Experiments in Oregon. Superphosphate, gypsum, and other fertilizers gave indications of the importance of sulfur in Southern Oregon experiments made by F. C. Reimer 1912.[12] Potassium sulfate, superphosphate, and gypsum gave increases in Central Oregon fertilizer experiments by the writer that same season,[13] indicating the great value of sulfur in that section. These experiments led to the first trials in Ore-

gon with elemental sulfur on soils in the Willamette and Deschutes valleys under irrigated conditions the following year, 1913. It was proved that increases secured by other sulfates could be obtained by use of elemental sulfur.

The importance of sulfur in connection with the results secured in these early experiments was perhaps first suggested by H. V. Tartar, at that time Chemist at the Oregon Experiment Station. In 1913 Professor Tartar published an article giving the new figures for the sulfur content of staple crops and calling attention to the unconscious use of sulfur in acid phosphate, gypsum, and other fertilizers,[14] thus questioning the sufficiency of sulfur. A brief announcement was made in 1914 by Professor Reimer[15] pointing out that lime-sulfur spray benefited legume cover crops beneath sprayed trees and indicated benefits from sulfur in this spray as well as in superphosphate, which also helped.

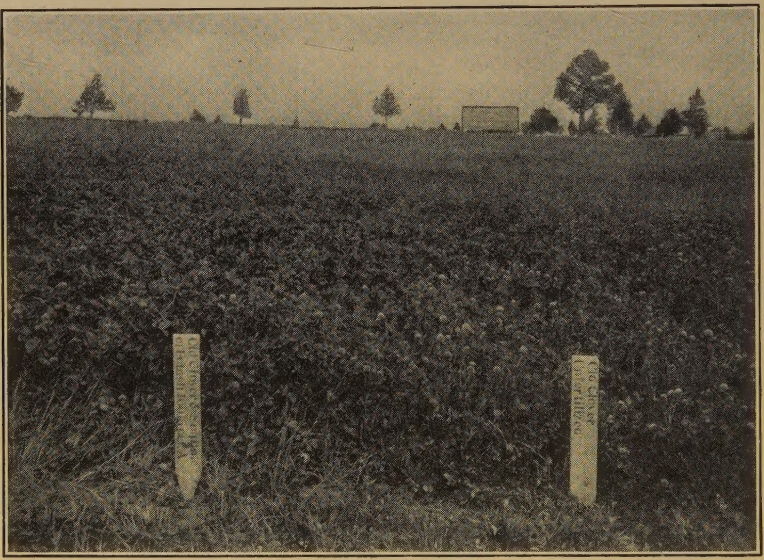

Fig. 3. Sulfate on clover. Redmond, 1912.

Professor Reimer used elemental sulfur in 1914 and obtained as good increases as with gypsum or superphosphate. Little or no increase was realized from rock phosphate. These Southern Oregon experiments were extended to fairly comprehensive fertilizer experiments during the following years. Fertilizers containing sulfur gave striking increases, whether flowers of sulfur, superphosphate, gypsum, iron sulfate, sulfate of ammonia, sulfate of potash, sulfate of magnesium, or sodium sulfate. In these trials nitrate of soda, monocalcium phosphate, chloride of potash, and ground limestone have had little effect upon alfalfa, showing that the increase is not due to liberation of phosphorus or potash or lack of lime in the soil. Chemical analyses proved that these soils were well supplied with potassium, lime, magnesium, and iron, were slightly alkaline, and were often low in sulfur.

Miller studied the effect of sulfur and sulfate in pot cultures[16] and found increased growth of plants in the greenhouse, indicating that sulfur was a direct aid in plant growth. He attributed the great increase in the nitrogen content of clover where sulfates were added to the increased action of legume bacteria, the sulfate causing greater development of nodules.

Sulfur studies have been conducted in the Deschutes Valley in Central Oregon with some minor interruptions since 1913, and in Southern Oregon and the Willamette Valley continuously since 1914. Field trials have been extended to most of the alfalfa-producing sections.

Fig. 4. Sulfur fertilizers plots in Southern Oregon.

The studies in Eastern Oregon were extended to Goose Lake Valley in 1915, and sulfur has doubled the yield on several fields there where results have been noted during the past eight years. Six years' results from field trials are available in Klamath county, and a single application of one hundred pounds on an acre has made in the six years an increase in yield of nearly two tons a year or a total of eleven for the period. There will be a 50 percent increase there from sulfur this, the seventh, year. The average increase from all sulfur trials in Deschutes Valley has been 1.8 tons an acre. During the past five years, sulfur trials have been carried on by the Experiment Station, and sulfur has been included in systematic (or complete) fertilizer experiments on many leading soil types of the state. Those have proved that at least 100,000 acres of alfalfa land in Oregon can be increased by one ton an acre in hay yields or a possible increase in hay value of $1,000,000 a year.

Cooperative extension demonstrations. Cooperative demonstrations have been carried on during the past several years with the county agents in Oregon. In Klamath county, in careful checks made on twenty-seven fields which have been treated with sulfur, the average increase

was 145 percent. On many of the soils, the increase was close to two tons an acre. Demonstration experiments comparing gypsum and sulfur were conducted in Grand Ronde Valley. Early results there favored gypsum, but sulfur is proving more economical in the long run. County agents report six cars of sulfur and eight cars of gypsum secured co-operatively during one season and applied to several thousand acres to provide sulfur for alfalfa lands. Including areas previously treated this brings the total area treated to sulfur in Oregon to about 25,000 acres. The average increase in hay on this will be at least a ton an acre, worth at $10 a ton, $250,000.

PLAN AND PURPOSE OF EXPERIMENTAL WORK WITH SULFUR

The writer started with sulfur investigations in Eastern Oregon in 1912 and 1913 and has been interested in the extending of these trials to

Fig. 5. Sulfur vs. no fertilizer, Southern Oregon.

different sections of the state. After the Soils department was organized in its present form sulfur studies centering around the field experiments were organized into a definite project for determining more accurately the functions and value of sulfur in relation to soil fertility. The trials were extended with the following objectives:

1. To determine the value and ultimate effect of the long-continued use of sulfur fertilizer on soil reaction and fertility. Also the value of important elements with and without sulfur.

2. To study the losses and gains of sulfur in soils from rainfall and drainage.

3. To determine the value of sulfur when applied to various crops and different soil types.

4. To determine the value of sulfur, gypsum, and aluminum sulfate used in connection with sweet clover in restoring the structure of drained alkali lands.

5. To determine the value of sulfur, manure, ground limestone, and ground rock phosphate combinations for making available the phosphorus needed by crops.

6. To determine the value of sulfur and sulfate applied alternately with ground limestone in humid sections.

When systematic field fertilizer trials were extended in 1918 to many additional soil types, plans were arranged to include trials of sulfur in each of these field fertilizer experiments. A lease had been arranged for protecting the sulfur experiments started by Reimer in Southern Oregon, and these experiments were extended and brought under irriga-

Fig. 6. Effect of sulfur in Klamath Basin.

tion. There are now sulfur experiments in Western Oregon that have been under continuous observation for nine years and in Southern Oregon eight years.

Sulfur content of soils. In connection with the detailed soil surveys official soil samples collected have been submitted to the department of Agricultural Chemistry; and since these chemical studies have included sulfur content, nearly all soil types in Willamette Valley and Southern Oregon have thus been tested for their sulfur content. Samples taken in the Willamette Valley have been from virgin soils, and this has been true of a number of samples secured and tested in connection with feasibility surveys on reclamation projects in Eastern Oregon.

These samples are usually taken to a depth of about 7 inches in the humid sections or to 12 inches depth for the surface samples in arid sections. The surface samples tested from Jackson county were taken from cropped fields to a depth of 15 inches. Available data as to sulfur content of Oregon soils employed in sulfur tests have been summarized

TABLE I. SULFUR CONTENT OF SOILS

Determinations by Department of Agricultural Chemistry

Area	Soil type	County	Depth in inches	Sulfur in 2,000,000 pounds surface soil	Phosphorus in 2,000,000 pounds surface soil
				lbs.	*lbs.*
Willamette Valley					
Hill	Melbourne clay loam	Washington	0–16	162	1400
	Carlton silt loam	Washington	0–16	124	1260
*	Carlton silty clay loam	Benton	0– 8	300	--------
*	Olympic silt loam	Marion	0– 8	580	--------
	Aiken silt loam	Washington	0–12	70	640
	Aiken silt loam	Yamhill	0–20	340	3400
	Aiken silty clay loam	Yamhill	0–10	540	4200
Old Valley	Powell silt loam	Multnomah	0–12	320	2540
	Willamette silt loam	Washington	0–18	260	3440
	Willamette silt loam	Yamhill	0–12	390	2240
	Hillsboro silt loam	Washington	0–30	260	1320
	Amity silt loam	Washington	0–18	360	2780
	Salem loam	Multnomah	0–12	640	2700
	Grande Ronde silty clay loam	Yamhill	0–20	700	2440
Recent sedimentary	Chehalis fine sandy loam	Yamhill	0–20	162	980
	Chehalis silty clay loam	Washington	0–14	140	1240
	Whiteson silt loam	Yamhill	0–12	320	1000
	Wapato silt loam	Washington	0–14	380	600
	Newberg clay loam	Multnomah	0–12	680	1580
	Wapato silt loam	Yamhill	0–12	460	1620
	Whiteson silt loam	Washington	0–18	1100	920
	Sauvie sandy loam	Multnomah	0–12	940	2440
Peat	Peat	Yamhill	0–12	3920	1880
	Peat	Washington	0–12	5000	2060
Southern Oregon					
	Corning clay loam	Josephine	0–12	140	960
	Aiken clay loam	Josephine	0–12	154	920
	Kirby loam	Josephine	0–12	180	1920
	Clawson clay loam	Josephine	0–12	220	240
	Columbia gravelly clay loam	Josephine	0–12	600	3840
	Salem fine sandy loam (coarse)	Jackson	0–15	300	1520
	Salem gravelly sandy loam	Jackson	0–15	380	1720
	Siskiyou coarse sandy loam	Jackson	0–15	380	2018
	Antelope clay adobe	Jackson	0–15	400	1280
	Phoenix clay adobe	Jackson	0–15	420	960
	Agate gravelly loam	Jackson	0–15	480	1140
	Agate gravelly sandy loam	Jackson	0–15	480	1640
	Salem clay loam	Jackson	0–15	540	1000
	Salem clay adobe	Jackson	0–15	540	1640
	Barron coarse sand	Jackson	0–15	560	1540
	Coker clay adobe	Jackson	0–15	560	1360
	Meyer silty clay loam	Jackson	0–15	580	1200
	Tolo loam	Jackson	0–15	580	1300
	Olympic clay adobe	Jackson	0–15	600	1380
	Climax clay adobe	Jackson	0–15	600	1000
	Sites fine sandy loam	Jackson	0–15	620	1580
	Medford fine sandy loam	Jackson	0–15	640	1040

	Salem fine sandy loam	Jackson	0–15	680	1920
	Medford loam	Jackson	0–15	720	1300
	Coleman gravelly loam	Jackson	0–15	740	1300
	Meyer clay adobe	Jackson	0–15	760	1180
	Medford gravelly clay loam	Jackson	0–15	760	1380
	Bellavista fine sandy loam	Jackson	0–15	800	1840
	Sites sandy loam	Jackson	0–15	819	900
	Neal silty clay loam	Jackson	0–15	900	1560
	Neal clay adobe	Jackson	0–15	900	1940
	Sam's loam	Jackson	0–15	980	1920
Greater John Day Project—Central Oregon					
	Fine sandy loam	Shutler flat	0–12	320	4200
	Fine sandy	Bench west of Butter Creek	0–12	240	4600
Lower Powder					
	Gravelly silt loams	--------------------	--------	150	1528
	Light silt loam	--------------------	--------	1440	934
	Gravelly loam	--------------------	--------	500	3230
Deschutes					
	Medium loamy sand	Redmond	--------	646	2009
	Medium loamy sand	Powell Butte	--------	160	--------
	Cropped vs. Virgin Soils				
Willamette Valley					
Abraham farm	Cultivated 50 years	Corvallis	--------	280	--------
Abraham farm	From fence line	Corvallis	--------	300	--------
Howd farm	Cultivated 50 years	Waldo hills	--------	460	--------
Howd farm	From fence line	Waldo hills	--------	580	--------
Central Oregon					
Bassett farm	Cultivated 14 years	Powell Butte	--------	140	--------
Bassett farm	From fence line	Powell Butte	--------	160	--------

Other regions	Authority	Range		Range
Earths Crust	Clarke	2200		1921
United States	Robinson	160–2600	U. S. Dept. of Ag. Bul. 122	
Illinois	Illinois Exp. Sta.	600–1000		1000–2000
Iowa	Brown and Kellogg	719– 938		
Ohio	Ames and Boltz	412– 800		
Indiana	Conner	480		
Eastern Washington	Olson and St. John	246– 712		
Wisconsin	Hart and Peterson	400–1200		
Kentucky	Shedd	360–1000		540–5550

in Table I. Samples of fields that have been cropped for a generation have been collected and analyzed, as have also adjacent virgin soils of undisturbed boundary or fence lines from sections where sulfur appears to be an important factor in connection with soil fertility.

The sulfur content of Southern Oregon soils runs from a hundred and forty pounds to eight hundred pounds in the plowed surface of an acre (six and two-thirds inches depth), or approximately 2,000,000 pounds. Many of the surface soils there contain less than 500 pounds of sulfur.

In the Willamette Valley the soils in the Valley floor contain a moderate amount of sulfur, usually 300 to 600 pounds in 2,000,000 pounds soil. The soils in the recently formed stream bottoms, with certain exceptions, contain 200 to 1,000 pounds of sulfur. According to analyses made, the soils in the hill lands in the Willamette Valley region are often low in sulfur, running frequently from 100 to 300 pounds in 2,000,000 pounds soil.

Few determinations have been made of Eastern Oregon soils. They frequently contain less than 500 pounds in the furrow stratum. The leading irrigated crop there is alfalfa, which for an average yield requires about twenty-five pounds of sulfur a season. Some Oregon soils contain ten times as much phosphorus as sulfur; while the leading crops, particularly in the arid and semi-arid sections, often require more sulfur than phosphorus and the crops grown require much less phosphorus than the corn crop in the central states.

Basaltic soils rather low in sulfur. Soil analyses from other states and replies to inquiries from experiment stations throughout the United States indicate that the basaltic soils in the Pacific Northwest offer a very great field for increased crop yields from the use of sulfur to supplement the moderate supply frequently found present in these soils. Basaltic rocks contain relatively small amounts of sulfur.[17] In the Great Basin sulfates are associated with the alkali, which is more common there. In the southern and eastern states the liberal use of sulfate-bearing fertilizers has probably overcome any deficiencies in sulfur that might have existed. There appears to be less sulfur than phosphorus in soils generally; different investigators have found losses of 20 to 40 percent in soils cropped for a generation as compared to virgin soil. Indiana[18] and Kansas[19] stations report moderate amounts of sulfur in soils of those states and find it readily available so that crop needs are considered satisfied. Stewart[5] considered sulfur from rainfall sufficient in Illinois to meet crop needs. Cropped Oregon soils show consistently lower amounts of sulfur present as shown in Table I from determinations by Oregon Experiment Station chemists.

Sulfur content of crops. Hart and Peterson[2] in 1911 reported new figures for sulfur content of crops. Reimer and Tartar[12] found that alfalfa from sulfur-treated plots contained a higher percentage of sulfur than alfalfa from untreated plots, and that it also contained sulfates. Similar increases in sulfur content of other crops due to use of sulfate-bearing fertilizers have been reported by Iowa, Wisconsin, and Kentucky experiment stations.[1] These increases appear to be associated with a higher protein content in sulfur-fertilized crops. Different investigators have shown that crops belonging to the legume and cabbage families

contain more sulfur than phosphorus. The sulfur content of crops is shown in Table II. It will be seen that legumes especially require nearly as much sulfur as phosphorus, while the supply of sulfur in soils is much lower.

TABLE II. SULFUR CONTENT OF CROPS

Determinations by Department of Agricultural Chemistry (Oregon Station Bulletin 197)

Crop	Number of determinations	Pounds in 1000 — Air dry — Sulfur	Air dry — Phosphorus	Oven dry — Sulfur	Oven dry — Phosphorus
Alfalfa	21	1.90	2.10	2.04	2.26
Red clover	23	1.00	1.70	1.08	1.42
Alsike clover	10	1.45	1.86	1.20	2.03
Sweet clover	3	1.49	2.03	1.59	2.17
Vetch	22	.87	2.31	.95	2.53
Peas	5	1.08	2.07	1.16	2.23
Timothy	3	.70	1.65	.75	1.77
Orchard grass	----	.44	1.41	.48	1.53
Bunch grass	----	.86	1.26	.92	1.35
Sunflowers	----	1.55	4.37	1.62	4.59
Wheat	3	1.13	3.53	1.28	3.54
Oats	5	1.27	3.52	1.40	3.88
Barley	6	1.00	3.74	1.13	4.21
Corn	2	1.09	3.14	1.21	3.50
*Potatoes	----	------	------	1.17	2.79
Onions	----	------	------	5.68	2.50
*Cabbage—Wisconsin	----	------	------	8.16	5.50
*Rape—Ohio	----	------	------	10.49	1.09
*White Beans	----	------	------	2.32	9.60
Soy-beans—Wisconsin	----	------	------	2.81	------

*Data from other experiment station publications.

Sulfur in rainfall and irrigation and drainage water. Coal smoke carries appreciable quantities of sulfur and probably influences the amount brought down to the land in rainfall where there is thick settlement or where industrial activities abound. Volcanic activity may at times influence accretion of sulfur by soil from the atmosphere.

Irrigation water may contribute sulfur to the soil. Water pumped for irrigation from a semi-artesian well and rising from a flow 218 feet below the surface at the Harney Branch Experiment Station, Oregon, was submitted to analysis. The Station Chemist's test shows that this water carries 2.01 pounds an acre foot of sulfur in sulfate form. Irrigation water used on Umatilla Branch Experiment Station is reported by Superintendent Dean to carry 2.29 pounds sulfur an acre foot. Coarse sand soil at that Station requires about five acre feet an acre of irrigation a season and this water appears to carry sufficient quantities of sulfur to supplement the soil supply for crops. Streams used for irrigation in the Great Basin and in the southwestern states carry appreciable amounts of sulfur in solution plus some in suspension.

Sulfur in rainfall. Precipitation for the past two rainy seasons at the Oregon Experiment Station, Corvallis, has been carefully collected and submitted to the Station Chemist for analysis for total sulfur. The pounds of sulfur an acre received in precipitation and amounts carried out in drainage from lysimeter tanks containing four feet of soil are shown in Table III, A, B, C.

TABLE III-A. SULFUR IN RAINFALL AND IN DRAINAGE FROM LYSIMETERS, 1920-21

(Determinations by department of Agricultural Chemistry, Oregon Experiment Station, from samples submitted by the Soils department.)

	Rainwater		Lysimeter No. 4 Willamette silty clay loam		Lysimeter No. 8 Dayton silty clay loam	
	Rain	Sulfur per acre	Percolated	Sulfur	Percolated	Sulfur per acre
	in.	*lbs.*	*in.*	*lbs.*	*in.*	*lbs.*
Winter 1920-21						
November	4.90	.350	2.31	--------	2.33	--------
December	7.97	.654	6.39	1.827	7.49	4.641
January	7.15	.118	7.19	3.499	6.84	3.586
February	5.38	.351	5.82	3.595	4.99	2.397
March	4.23	Lost	3.10	1.936	3.13	1.825
April	1.99	------	.07	T	.01	T
	31.62	------	------	--------	------	--------

TABLE III-B. WILLAMETTE SILTY CLAY LOAM, 1921-22

	Rain		Lysimeters Nos. 1 and 4 Manured		Lysimeters Nos. 2 and 3 Untreated	
	in.		*in.*	*lbs.*	*in.*	*lbs.*
Winter 1921-22						
November	5.36	Partial	8.02	11.83	9.40	10.66
December	3.48	data	3.64	4.49	3.62	5.04
January	3.80	only	3.75	3.28	4.39	7.33
February	4.85	------	4.33	2.91	5.54	10.02
March	5.81	------	3.65	2.10	4.76	8.26
April	1.77	------	.68	.50	1.15	2.42
				25.11		43.73

TABLE III-C. SULFUR IN DRAINAGE WATER FROM LYSIMETER, 1922-1923

		Willamette silty clay loam							
		Lysimeter 1. Untreated		2. Manured, limed 20 tons to acre 3 tons to acre		3. Manured 20 tons to acre		4. Limed 3 tons to acre	
	Rain	Percolate	Sulfur	Percolate	Sulfur	Percolate	Sulfur	Percolate	Sulfur
	in.	*in.*	*lbs.*	*in.*	*lbs.*	*in.*	*lbs.*	*in.*	*lbs.*
1922									
Nov.	3.07	--------	--------	2.75	3.85	2.59	3.35	2.55	2.16
Dec.	11.11	3.09	2.750	8.79	11.90	11.15	24.05	11.01	7.83
1923									
Jan.	10.88	6.68	3.890	8.43	19.15	10.05	23.52	10.08	10.24
Feb.	2.16	2.04	.74	2.54	4.79	3.19	5.29	2.52	1.34
Mar.	2.57	.86	.37	1.55	2.64	1.65	2.35	1.48	.91
Totals	29.79	12.67	7.75	24.06	42.33	28.63	58.56	27.64	22.48

The data indicate that only a few pounds of sulfur may be expected from precipitation, while drainage loss may run twenty to forty-five pounds or more an acre, indicating an important net loss. In Western Oregon, section B of the percolation data shows a much higher loss from heavy soils that have been manured. Section C shows that lime is effective in liberating sulfur.

Stewart reports 45.1 pounds an acre a year received in precipitation at the Illinois station as a seven-year average.[5] MacIntire[20] found 49.6 pounds of sulfur an acre added by precipitation at Knoxville, Ten-

nessee. Hart and Peterson[2] found the amount received annually to be 7 pounds in Wisconsin. The Ohio Experiment Station[4] cites Russian data showing 9 pounds in country and 72 pounds near towns received from rainfall and estimates that 6 to 7 pounds an acre a year is received in the United States.

Loss of sulfur in drainage has been estimated at 20 to 80 pounds an acre from data collected at Rothamsted, England. Lyon reports that in New York sulfur in drainage from fallow tanks about equalled that removed by crop and drainage in cropped tanks.

Wisconsin studies[2] place loss in drainage at three times that received by rainfall, while Tennessee studies[20] show annual loss from lysimeter tanks at 13 to 64 pounds an acre a year, depending upon treatment applied.

FIELD EXPERIMENTS

Important early field experiments. Experimental results leading to use of sulfur as a fertilizer in Oregon are out of print and are therefore reviewed here for convenience. See Table IV.

TABLE IV-A. VALUE OF FERTILIZERS AND THEIR RELATION TO ECONOMICAL USE OF IRRIGATION WATER

Deschutes Medium Sandy Loam, Redmond, 1912.

Crop	Irrigation, total depth	Fertilizers per acre	—Yield per— acre	water inch	—Gain in— yield	value	Cost of fertilizer	Profit (or loss)
	in		*tons*	*tons*	*tons*			
Alfalfa	21	None	3.00	.143	------	------	------	------
Alfalfa	21	Potassium sulfate 160	3.96	.186	.96	$8.68	$4.00	$4.68
Alfalfa	21	Gypsum 60	3.40	.162	.41	3.69	.45	3.24
Alfalfa	21	Potassium chloride 160	3.27	.165	.27	2.43	4.00	−1.57
Old clover	24	None	3.33	.138	------	------	------	------
Old clover	24	Potassium sulfate 160	5.04	.210	1.71	15.39	4.00	11.39
Old clover	24	Gypsum 60	3.48	.145	.25	2.25	.45	1.80

TABLE IV-B. FERTILIZER USED AND ALFALFA YIELDS, MEDFORD FINE SANDY LOAM

Plots one-tenth acre in size. Fertilizer applied April 11, 1912

Plot	Application		Yield first cutting tons an acre
		lbs.	*tons*
1	Dried blood	50	1.85
2	Superphosphate	50	2.45
3	Muriate of potash	25	1.65
4	Dried blood	50	2.35
	Superphosphate	50	------
5	Dried blood	50	1.95
	Muriate of potash	25	------
6	Superphosphate	100	2.09
	Muriate of potash	25	------
7	Dried blood	25	2.26
	Superphosphate	50	------
	Muriate of potash	25	------
8	Gypsum	40	2.07
9	Checks (Ave. 7 trials)	------	1.76

The experiment conducted on sandy loam in the Deschutes Valley in 1912 (Table IV-a) was planned to determine whether the local practice of using gypsum was not due to its effect in releasing potash for crops. The results of the experiment indicated very strongly that crop increases obtained were mainly due to sulfur contained in the applications. The following year elemental sulfur was used which about doubled the yields, showing that it was sulfur and not potash that caused the increased yield.

In the Rogue River Valley (Table IV-b), the superphosphate and gypsum applied to Medford fine sandy loam produced a denser stand of dark green color and increased yields, while other fertilizers did not cause difference in appearance from the check plots; the alfalfa possessing a pale green color. The increase obtained by superphosphate was

Fig. 7. Sulfur yield 8¾ tons treated, 5 tons untreated, Klamath.

at the time attributed to phosphorus, but trials the following year gave no increase from use of raw rock phosphate, and in 1914 yields of alfalfa were about doubled by the use of sulfur in elemental form and in superphosphate and iron sulfate as well. Rock phosphate had no effect, therefore it was the sulfur and not the phosphorus that caused the increased yield and rich color of alfalfa.

PROGRESS OF SOUTHERN OREGON EXPERIMENTS

More permanent experiments in Southern Oregon initiated in 1915 were planned[1] to determine definitely whether sulfur was responsible for increases obtained from sulfate-bearing fertilizers on alfalfa;[2] the value of various sulfates, and[3] whether sulfur acted directly as a plant food or

indirectly as a stimulant and liberator of important elements of fertility. The experiment field is located seven miles north of Medford on antelope clay adobe soil.

Effect and value of sulfur fertilizer. Fertilizers containing phosphorus alone and those having this important plant food and sulfur also were applied in amounts calculated to provide the same number of pounds of elemental sulfur whatever sulfur-bearing compounds were used, as shown in Table V. These experiments seem to prove that increases obtained were due to sulfur in various applications and could be secured by use of elemental sulfur. Little increase was obtained from forms of phosphorus containing no sulfur. On this adobe soil alfalfa runs out after a few years and should be plowed up in five or six years. When sulfur is applied the stand endures longer than with no sulfur.

Fig. 8. Effect of sulfur on alsike, Fort Klamath.

This antelope clay adobe soil is well supplied with potassium, calcium, magnesium, organic matter, and calcium. It is low in phosphorus and very low in sulfur. It is neutral in reaction. When the experiment was started the alfalfa was two years old, thick, and had some nodules throughout.

Wherever sulfur or sulfates were applied, striking increases in yields were obtained, with fewer weeds. The elemental sulfur did not oxidize so as to become fully effective the first season. During recent years indication of need of supplementing the supply of phosphorus has increased. The larger yields secured by sulfur may be expected to hasten depletion of the low supply of phosphorus in this soil to a point where it will need to be supplemented. The results of this experiment show that the increase caused by sulfur is not due to liberation of phosphorus. The large amount of lime present in this soil favors oxidation of sulfur into available sulfates.

The east half of this 1915 series was retreated in March of 1917 and again in March, 1920. The west half of this series and others where not retreated have fallen off in yield the fourth and fifth years.

Duration and ultimate effect of treatment. This experiment at Medford, one of the older field experiments still under way, is of value as

indicating the duration and ultimate effect of sulfur applications. The heavy applications of sulfur in this and other ranges of these experiment fields have shown no injurious effects from the applications, and the only apparent result has been increased yields. The soil is well supplied with calcium, and only the slightest indications of acidity can be found where heavy applications have been made. It is not to be expected that a simple element will permanently maintain fertility, and the time is likely to come when it will pay to supplement the supply of phosphorus and possibly other elements to give a permanent system of agriculture.

TABLE V. VALUE AND EFFECT OF SULFUR FERTILIZERS ON ANTELOPE CLAY ADOBE—OREGON EXPERIMENT STATION

1915 Series, Reimer Plots, Soil Experiment Field, Medford, 1915-1921. Yield per Acre, Tons. East ½ Retreated 1917-1920.

Treatment	Plot		1915	1916	1917	1918	1919	1920	1921	Alfalfa T. per A. 7 year Ave. 15-21	Inc.	Ave. Annual net gain from fertilizers
											tons	
		E	1.495	.480	.380	.190	.560	.435	.520	.580	-------	-------
Check	1	W	1.495	.480	.380	.250	.400	.690	.610	.615	-------	-------
Gypsum 595.0		E	5.440	4.920	3.040	1.070	2.440	3.250	2.145	3.180	2.524	$23.98
1 x 8 rds.	2	W	5.440	4.920	2.480	.570	2.790	1.590	1.160	2.707	2.097	20.55
Monocalcic phosphate		E	1.590	.710	.470	.260	.380	.670	.560	.663	0.001	–4.37
410.0	3	W	1.590	.710	.480	.270	.330	.410	.520	.616	0.006	–1.40
Superphos.		E	5.460	4.820	3.000	1.080	2.540	3.690	2.145	3.248	2.586	19.68
823.0	4	W	5.460	4.820	3.220	.580	2.760	1.380	1.065	2.755	2.145	19.39
		E	1.080	.335	.330	.350	.520	.725	.988	.620	-------	-------
Check	5	W	1.080	.335	.350	.280	.530	.660	.710	.563	-------	-------
Sulfur		E	2.640	5.270	3.700	1.150	3.110	3.350	2.868	3.155	2.493	24.06
100.0	6	W	2.640	5.270	3.920	.600	3.020	1.455	1.295	2.600	1.990	19.61
Sulfur		E	5.010	5.380	3.780	1.030	4.900	3.510	3.040	3.807	3.245	29.87
300.0	7	W	5.010	5.380	4.020	.850	4.580	4.765	3.995	4.086	3.476	33.90
Iron sulfate		E	5.610	5.780	4.480	1.360	3.990	2.340	4.410	3.996	3.334	32.54
842.0	8	W	5.610	5.780	4.160	.900	5.170	3.540	3.184	4.049	3.439	33.79
		E	1.085	.245	.760	.220	.380	1.700	1.110	.786	-------	-------
Check	9	W	1.085	.245	.760	.240	.380	.880	.985	.653	-------	-------

Value of fertilizers with and without sulfur (Table VI). The January, 1916 series (Table VI) was designed not only to learn the value of various elements with and without sulfur, but also to determine whether sulfur caused increased yield due to liberation of potassium or other elements. Plots 1 and 2 proved to be a shallow soil. Sulfur and sulfates continue to show large increases in this series. The more available sulfates work most promptly, and heavy applications gave larger increases the first year than light applications of sulfur. Applications of phosphorus, potassium, and nitrogen in available forms and in compounds free from sulfur gave little increase, while compounds containing these elements with sulfur or in sulfate form gave increases and good color similar to the results with sulfur alone. This fact shows that increased yields caused by sulfur were not due to liberation of other important plant foods.

Lime vs. sulfur. A new series of plots was started November, 1916 primarily to test the value of lime as compared to sulfur on this soil. Table VII gives the plan and results obtained. Use of lime has had no

TABLE VI. EFFECT OF FERTILIZER WITH AND WITHOUT SULFUR

January 1916 series: Reimer Plots, Oregon Experiment Station, Soil Experiment Field, Medford. Retreated 1920 except 6 and 17. Plot 9 received some sulfur bearing material probably 1920

Plot	Treatment — Fertilizer	Treatment — Pounds per acre	Yield per acre Average for six years 1916-1921	Ave. gain in yield per acre	Ave. annual net gain from fertilizers
		lbs.	tons	tons	
1	Check	0	.493	--------	--------
2	Sulfur	600	2.036	1.502	$ 9.02
3	Sulfur	100	2.305	1.771	17.05
4	Sulfur	300	2.620	2.086	18.86
5	Gypsum	595	2.870	2.336	21.87
6	Mococo Residue (not retreated)	1541	2.725	2.191	17.41
7	Monocalcic Phosphate	317	.595	.061	–.97
8	Superphosphate	823	2.605	2.071	15.91
9	*Muriate of Potash (4 yrs. Some S '20)	534	1.165	.631	2.31
10	Sulfate of potash	594	2.445	1.911	13.17
11	Check	0	.545	--------	--------
12	Nitrate of Soda	558	.575	.041	–5.17
13	Sulfate of Ammonia	423	2.675	2.141	15.77
14	Iron sulfate	870	2.685	2.151	20.06
15	Magnesium sulfate	782	2.685	2.151	18.80
16	Sodium sulfate	1033	2.255	1.721	15.49
17	Pyrites (not retreated)	263	.890	.356	2.68
18	Check	0	.440	.094	--------

*4 yr. ave.

TABLE VII. COMPARISON OF LIME WITH SULFUR

November 1916 Series: Reimer Plots, Oregon Experiment Station, Soil Experiment Field, Medford

Plot	Treatment fertilizer	Amt. per acre	Cost	Ave.	Two	Yield per acre Alfalfa Ave. for 5 years 17-21	Incr.	Value	Net gain
		lbs.							
1	Check—harrowed	0	--------	--------	--------	.665	--------	--------	--------
2	Pyrites—harrowed	477	$2.38	$0.48	$0.96	1.485	.689	$6.86	$5.93
3	Pyrites—not harrowed	477	2.38	.48	.96	1.725	.929	9.29	8.33
4	Sulfur—not harrowed	100	2.00	.40	.80	2.925	2.129	21.29	20.49
5	Gypsum—not harrowed	595	4.47	.89	1.78	3.250	2.454	24.54	22.76
6	Quicklime—not harrowed	2000	10.00	2.00	4.00	.865	.069	.69	–3.31
7	Ground limestone—not harrowed	2000	5.00	1.00	2.00	.817	.026	.26	–1.74
8	Check—not harrowed	0	--------	--------	--------	.928	--------	--------	--------

Avg. Check .796

Plots retreated with same amounts of fertilizer in March, 1920. No yields are given for plots 7 and 8 for 1919 and hence the average yield is a four year average.

appreciable effect, showing that sulfur has not liberated this element for plants. Quicklime, like heavy sulfur applications, tends to mellow the surface soil but does not increase yields as does sulfur or sulfates. Due to early fall application this experiment gave time for oxidation, and much better results were secured the following growing season. Harrowing in pyrites applied on this heavy soil in the fall did not appear to hasten their action.

Sulfur and rock phosphate. Series of plots of antelope clay adobe were treated in the spring of 1917 and of 1919 to test the value of sulfur, sulfur and rock phosphate, gypsum, gypsum and rock phosphate, and superphosphate. The results of this experiment appear in Table IX.

Soil in plots 6 to 11 is slightly better than that in plots 1 to 5 inclusive. There is a growing indication of increase in yield where sulfur is supplemented by phosphate. Sulfur and rock phosphate applied together may aid prompt oxidation of sulfur and liberation of the phosphorus and ultimately prove more economical than acid phosphate.

TABLE VIII. COMPARISON OF SULFUR AND PHOSPHORUS

1917 Series: Reimer Plots, Oregon Experiment Station, Soil Experiment Field, Medford.

Plot	Treatment fertilizer	Amount per acre	Retreatments 4-15-19	Retreatments 3-1-20	Ave. yield per acre 6 yrs. 1917-22	Incr.	Value	Net gain
		lbs.	*lbs.*	*lbs.*	*tons*			
1	Check	0	0	0	.439	--------	--------	--------
2	Superphosphate	412	823	412	2.051	1.645	$16.45	$11.65
3	Gypsum	298	595	298	2.066	1.666	16.66	13.29
	Rock phosphate	281	564	281	--------	--------	--------	--------
4	Gypsum	298	595	298	1.937	1.531	15.31	13.82
5	Check	0	0	0	.345	--------	--------	--------
7	Superphosphate	412	823	412	2.238	1.832	18.32	11.64
	Rock phosphate	281	564	281	--------	--------	--------	--------
8	Sulfur	100	50	50	2.121	1.715	17.15	16.48
9	Sulfur	100	50	50	2.256	1.856	18.56	17.89
10	Sulfur	200	100	100	2.663	2.257	22.57	19.35
	Rock phosphate	281	564	281	--------	--------	--------	--------
11	Sulfur	200	100	100	2.043	1.637	16.37	15.33
12	Check	0	0	0	.435	--------	--------	--------

TABLE IX. COMPARISON OF SULFUR AND ROCK PHOSPHATE WITH SOLUBLE PHOSPHATE

1919 Series: Reimer Plots, Oregon Experiment Station, Soil Experiment Field, Medford.

Plot	Treatment fertilizer		Amount per acre		Yield per acre Average for 3 yrs. '20-'22	Increase	Value	Net
		lbs.			*tons*			
1	Check	0	--------	--------	1.540	--------	--------	--------
2	Superphosphate	412	$7.21	2.40	2.980	1.44	$14.40	$12.00
3	Sulfur	50	1.00	--------	--------	--------	--------	--------
	Rock phosphate	281	2.81	1.27	2.690	1.15	11.50	10.23
4	Sulfur	50	1.00	--------	2.561	1.021	10.21	6.88
5	Superphosphate	412	7.21	2.40	2.429	.889	8.89	6.49
6	Sulfur	50	1.00	--------	--------	--------	--------	--------
	Rock phosphate	281	2.81	1.27	2.389	.849	8.49	7.22
7	Sulfur	50	1.00	--------	2.020	.48	4.80	4.47

Treatment applied April 15, 1919.

Best rate of application. An experiment begun in 1917 by Professor Reimer on antelope clay adobe to determine the most profitable rate to apply sulfur is still being maintained. Results show (Table X) that on heavy soils the most economical returns may be expected from applying one hundred pounds an acre every three or four years.

In Deschutes fifty, eighty, one hundred, and two hundred pounds an acre, and in Union county fifty, one hundred, and two hundred pounds have been applied. One hundred pounds should meet requirements of increased yields for three to four years. On sandy soils in Deschutes Valley where, with heavy irrigation and rapid drainage, lighter and more frequent application is good practice, only sixty to eighty pounds every two or three years is necessary.

TABLE X. DIFFERENT RATES OF APPLICATION FOR SULFUR

1917 Sulfur Series, Reimer Plots, Oregon Experiment Station, Soil Experiment Field, Medford.

Plot	Treatment fertilizer	Amount per acre	Cost per acre	Yield per acre ave. for 3 yrs. 1918-21
		lbs.		*lbs.*
1	Sulfur	100	$2.00	2.063
2	Sulfur	200	4.00	2.290
3	Sulfur	300	6.00	2.173
4	Sulfur	400	8.00	2.123

Treated November, 1917.

No yield given for 1919 and hence the average is a three-year average although the series has run four years. All plots did not receive same amount of water, due to slope of land.

On some soils the initial application may help to establish alfalfa and overcome the deficiency so that a lighter treatment will suffice; or, in some cases, no retreatment may be required. Retreatment may be unnecessary on some acid red hill soils, and excessive amounts would tend to aggravate acidity.

Work on antelope adobe indicates that retreatments are needed each four years.

PROGRESS OF EASTERN OREGON EXPERIMENTS

Unfortunately the irrigation demonstration farm at Redmond was discontinued in 1913, but the fertilizer plots there gave similar yields and differences in 1913 as in the preceding year.

In the spring of 1913 one hundred pounds of commercial powdered sulfur was applied to one acre, with an increase in yield of nearly two tons an acre over adjoining, untreated, check plots.

In 1915 three one-acre plots in the Deschutes medium sand area were treated as above and on two of these, the Brown and Landis farms, practically two tons an acre increase was obtained each year for three years thereafter.

Effect of sulfur on various soils of Eastern or Central Oregon. (Table XI). Three fertilizer experiments were started on the Deschutes sandy loam in 1918. The plan and results covering a three-year period are given in Table XI. The second season of the trial appeared to be favorable for slightly larger yields, and the striking increases obtained from sulfur and sulfate treatments were slightly less apparent the third year of the experiment, indicating need of retreatment. The effect of sulfur has been much less the fourth year on this soil. Except in one field, these experiments were interrupted the fourth season, as a field agent could not be maintained. They proved that use of sulfur was applicable to the different project lands in Central Oregon.

Use of sulfur in comparison with gypsum (Table XII). Good gypsum contains about eighteen pounds of sulfur in one-hundred pounds of material in available form. Gypsum is mined near Huntington, Eastern Oregon, within a short distance of the Malheur, Powder, and Grande Ronde valleys, and is readily secured at most trading points in the state. Because it is readily secured and easy to apply, farmers have been inclined to continue its use under conditions where it is evidently effective

TABLE XI. EXPERIMENTS ON PROJECTS IN EASTERN OREGON

		Crop—Alfalfa '18, '19, '20. Avg. tons per acre	Avg. increase tons	3 yrs. Avg. Net value of increase
Van Matre plots, Sisters, Ore.		*tons*	*tons*	
1 Muriate of potash	160	2.95	0.38	$1.00
2 Sulfate of potash	160	3.10	0.53	0.50
3 Sulfur	100	3.51	0.94	7.40
4 Check	0	2.57	------	------
5 Superphosphate	320	3.22	0.65	0.90
6 Nitrate of soda	80	3.14	0.57	3.30
7 Check	0	2.57	------	------
8 Gypsum	50	3.05	0.48	4.55
Becker plots, Tumalo				
1 Gypsum	50	2.74	0.85	8.25
2 Muriate of potash	160	1.95	0.06	–4.60
3 Superphosphate	320	2.39	0.50	–0.60
4 Nitrate of soda	80	2.32	0.43	1.90
5 Sulfate of potash	160	2.85	0.96	4.80
6 Sulfur	80	2.97	1.08	9.20
7 Check	0	1.89	------	------
Martin plots, Redmond				
1 Check	0	4.07	------	------
2 Muriate of potash	160	4.07	0.00	------
3 Superphosphate	320	5.02	0.95	4.70
4 Nitrate of soda	80	5.14	1.07	5.10
5 Sulfate of potash	160	5.78	1.71	12.30
6 Sulfur	80	5.96	1.89	17.30

TABLE XII. COMPARISON OF SULFUR VS. GYPSUM
Deschutes Valley Sandy Loam Soils

Plot	Treatment — Fertilizer	Treatment — Amount per acre	Yield, tons per acre
	W. B. Chapman—2 miles north of Redmond, 1918.		
Alfalfa		*lbs.*	*tons*
1	Sulfur	80	1.44
2	Check	0	.70
3	Gypsum	50	1.36
	H. Solburg—3 miles northwest of Redmond.		
1	Sulfur	40	1.88
2	Gypsum	50	1.51
	Brown—3 miles north of Tumalo.		
1	Sulfur	------	2.69
2	Gypsum	------	2.08
	P. J. Peterson—Grange Hall.		
1	Sulfur	160	2.30
2	Gypsum	50	1.54
	M. E. Landes—2 miles west of Redmond, 1918.		
Alfalfa			
1	Sulfur	------	5.44
2	Check	------	2.38
3	Gypsum	------	2.79
	E. Atkinson—2 miles southwest of Redmond, 1919.		
Alfalfa			
1	Sulfur	80	2.55
2	Check	0	1.05
	W. R. Davidson—Terrebone, 1919.		
Alfalfa			
1	Sulfur	100	6.50
2	Gypsum	50	5.39
	H. Solberg—3 miles northwest Tumalo.		
Alfalfa			
1	Sulfur 1918	40	1.15
2	Sulfur 1919	------	1.70
	Average		
1	Sulfur	------	3.26
2	Gypsum	------	2.45
3	Check	------	1.38

in supplying available sulfur. The disagreeable feature of applying sulfur can be largely overcome by mixing it with damp sand just before the application is made; it can then be applied with a land-plaster spreader.

In the spring of 1918 seven demonstration experiments, in addition to the Eastern Oregon experiments just reported, were started in the Deschutes Valley on medium sandy loam to test further the value of sulfur as compared with gypsum. Unfortunately these experiments were located on various ranches, and accurate yields were not obtained after the first season. The plan of these trials and yields is given in Table XII. Applications were made before alfalfa began growth. The alfalfa was usually renovated and was irrigated so that the sulfur became rapidly oxidized, and sulfur plots frequently out-yielded the gypsum plots the first season.

Rate and form of application. Six cooperative demonstration experiments were conducted in Union county by County Agent Paul Spillman. Applications to alfalfa plots were made in the spring of 1917, gypsum being applied at the rate of fifty, one hundred, two hundred, three hundred pounds to an acre and sulfur at the rate of one hundred and two hundred pounds an acre. Three fields employed were clay loam, two were dark silt loam, and two were sandy loam soils. Only one of the soils received irrigation, and, as the first season was a dry one, results were secured from only the irrigated field. A dark silt loam soil employed belonged to Mr. Homer Carnes, located near North Powder. Two hundred pounds of sulfur increased the yield three hundred pounds, while a like amount of gypsum increased the yield 450 pounds the first season. A hundred-pound application of sulfur gave a season's increase in yield of 612 pounds, while a hundred-pound application of land-plaster gave an increased yield of 797 pounds. The following year all seven trials gave substantial increases from applications of sulfur and sulfate. Accurate yields were not obtained after the second year. The results show greatest profits from using 200 pounds of gypsum or 100 pounds of sulfur on alfalfa meadows. By 1920 it was found that the fifty-pound and one-hundred-pound applications of gypsum caused little appreciable increase in growth, while the increase in yield for two-hundred- and three-hundred pound applications was still apparent and the one-hundred- and two-hundred-pound applications of sulfur were still giving marked increases. The fifth season the increase from the sulfured plots appeared to be as marked as in previous years, while the gypsum treatment had run out. Data of the first two seasons show that the gypsum was most effective in the season of 1918, but the sulfur had become most effective by 1919, showing that it is the more economical and permanent treatment.

As an average of all trials to and including 1920, sulfur applications in the Deschutes Valley have given a net profit of $18.00 over untreated plots, while gypsum has given an increased net profit of $6.50 or less than half as much. These results emphasize the need for sulfur.

New fertilizer experiments in Eastern Oregon (Table XIII). A fertilizer experiment was initiated on Deschutes medium sandy loam in the spring of 1921 planned with the sulfur problem in mind and arranged to include a series of plots cropped to alfalfa for rotation with others

receiving similar treatment and cropped to grain and potatoes. The plan of experiments and the results obtained are summarized in Table XIII. This soil is medium sandy loam of medium depth. A light application of gypsum had been used to start the alfalfa. This lessened the results from sulfur the first year. The liberal amount of irrigation used and the limited quantity and percent of plant food tend to lessen the duration

TABLE XIII. RECENT FERTILITY TRIALS IN DESCHUTES VALLEY, EASTERN OREGON

Deschutes sandy loam, Adams tract, Redmond

		Rate per acre	Cost of treatment	Yield per acre 1921	Yield per acre 1922	Two-year increase from fertilizer	Net value* two-year increase
Alfalfa							
		lbs.		*tons*	*tons*		
1	Check	......	......	2.70	3.59	......	......
2	Sulfur	100	$2.00	2.99	3.84	.48	2.30
3	Gypsum	200	1.50	2.96	3.70	.26	1.10
4	Rock phosphate	600	6.00	2.98	3.68	.26	–3.40
5	Triple phosphate	100	2.50	3.01	3.71	.32	.70
6	Check	......	......	2.81	3.74	......	......
7	Potassium chloride	100	3.50	3.02	3.98	.60	2.50
8	Potassium sulfate	100	3.50	3.02	4.57	1.19	8.40
9	Nitrate of soda	100	3.50	2.83	3.74	.17	–1.80
10	Ammonium sulfate	200	8.00	3.04	3.91	.55	–2.50
11	Check	......	......	2.80	3.57	......	......
12	Sodium nitrate	100	3.50	3.05	3.86	.51	–2.60
	Potassium chloride	100	3.50	......	......	......	......
13	Sodium nitrate	100	3.50	2.97	3.69	.26	–.90
	Triple acid phosphate	100	2.50	......	......	......	......
14	Potassium chloride	100	3.50	3.02	3.91	.53	1.80
	Triple acid phosphate	100	2.50	......	......	......	......
15	Triple acid phosphate	100	2.50	2.99	3.72	.31	.60
	Potassium chloride	100	3.50	......	......	......	......
	Sodium nitrate	100	3.50	......	......	......	......
16	Check	......	......	2.78	3.65	......	......
17	Sulfur	100	2.00	2.95	......	.18	–.20
	Manure	10T	......	......	......	......	......
18	Rock phosphate	600	6.00	2.98	......	.21	–3.90
	Manure	10T	......	......	......	......	......
Average of checks		......	......	2.77	3.63	......	......
Potatoes				*bu.*			
1	Check	......	......	82	225	......	......
2	Sulfur	100	2.00	98	245	38	20.80
3	Gypsum	200	1.50	103	244	42	22.70
4	Rock phosphate	600	6.00	100	245	40	18.00
5	Triple acid phosphate	100	2.50	88	249	32	16.70
6	Check	......	......	69	223	......	......
7	Potassium chloride	100	3.50	119	250	64	34.90
8	Potassium sulfate	100	3.50	116	244	60	32.50
9	Nitrate of soda	100	3.50	103	249	47	24.70
10	Ammonium sulfate	200	8.00	118	253	66	34.60
11	Check	......	......	91	233	19	11.40
12	Sodium nitrate	100	3.50	105	245	45	23.50
	Potassium chloride	100	3.50	......	......	......	......
13	Sodium nitrate	100	3.50	112	246	53	28.30
	Triple acid phosphate	100	2.50	......	......	......	......
14	Potassium chloride	100	3.50	117	247	59	31.90
	Triple acid phosphate	100	2.50	......	......	......	......
15	Triple acid phosphate	100	2.50	119	250	64	35.90
	Potassium chloride	100	3.50	......	......	......	......
	Sodium nitrate	100	3.50	......	......	......	......
16	Check	......	......	87	233	15	9.00
17	Sulfur	100	2.00	......	......	......	......
	Manure	10T	......	......	......	......	......
18	Rock phosphate	600	6.00	......	......	......	......
	Manure	10T	......	......	......	......	......
Average of checks		......	......	77	228	......	......

*Hay at $10.00 per ton. Potatoes at 50c per bu.

of the sulfur treatment. Comparatively light, frequent applications of sulfur and sulfate fertilizers will consequently be most economical. In recent years there is also a growing indication that in time potash will need to be supplied. This soil responds to nitrogen unless it is supplied by rotation with legumes. During seven seasons' fertilizer experiments with potatoes conducted in this section potash has been found to pay well. The form of potash fertilizer that has paid best has been sulfate of potash. Ammonium sulfate on non-legume sod has given good results; where increase has been obtained from the use of sulfur or ammonium sulfate, the results may be partly due to the checking of potato scab. Nitrogen can be obtained under Deschutes Valley conditions by rotation with legumes. Sulfur can be obtained more cheaply in elemental form.

TABLE XIV. SUMMARY OF FERTILIZER TRIALS, DESCHUTES VALLEY, EASTERN OREGON

Trials mainly in 1912 and 1918, 1919, 1920. Oregon Experiment Station Department of Soils. Four-year average.

Fertilizer	Crop	No. of trials	Ave. rate per acre Applied	Ave. rate per acre Value	Ave. yield per acre	Average increase over check plot	Net value* of increase
Sulfur	Alfalfa	8	80	$3.20	4.35	1.8 T.	$18.00
Sulfur	Oats	1	80	3.20	30 bu.	5 bu.	.80
Gypsum	Alfalfa	10	52.5	.37	3.75 T.	.67 T.	6.51
Phosphorus	Alfalfa	6	280	5.12	3.95 T.	1.10 T.	8.44
Phosphorus	Barley	1	320	5.12	66.2 bu.	3.40 bu.	1.30
Nitrogen	Alfalfa	6	80	3.20	4.00 T.	1.14 T.	9.80
Nitrogen	Barley	1	160	6.40	69 bu.	8.4 bu.	3.05
Manure	Barley	1	10 T	-------	61.7 bu.	1.1 bu.	
Muriate of potash	Alfalfa	4	140	13.90	3.09 T.	.62 T.	6.20
Muriate of potash	Potatoes	7	130	11.55	113 bu.	24. bu.	8.10
Sulfate of potash	Clover	1	160	14.40	5.04 T.	1.71 T.	10.90
Sulfate of potash	Alfalfa	2	120	8.75	5.23 T.	1.33 T.	8.92
Sulfate of potash	Potatoes	11	160	14.40	235 bu.	90 bu.	40.20
Kemfert	Potatoes	7	126	7.94	94.4	7.6 bu.	–3.76
Kelpchar	Potatoes	4	240	15.15	98.5	25.72 bu.	–1.54

* Hay at $10.00 per ton. Potatoes at 50c per bu.

Cost, value, and profit from fertilizers used in Deschutes Valley, Eastern Oregon (Table XIV). A summary of all representative fertilizer trials in the Deschutes Valley is given in Table XIV. This table is arranged to show the cost, value, and profits from fertilizer treatments, using the market prices for fertilizers and products. The largest profit has been realized from potash on potatoes, the next largest net profit an acre has been realized from the use of sulfur on alfalfa. Sulfur trials have been made on most of the alfalfa soils in the state and nearly all of the important alfalfa areas respond to sulfur to a marked extent. There appears to be little relation between soil texture and reaction from sulfur treatment. Free working soils perhaps oxidize a little more sulfur and the results seem to be a little more rapid on such land. Under irrigation, however, the duration of the sulfur treatment is not so long on sandy as on the heavy-textured soils. There does appear to be a fairly close relation between the sulfur content of soils and their response to sulfur treatment. These experiments were retreated and extended at the beginning of the growing season of 1923 to study the effect of different forms of sulfur and different rates of application.

Sulfur versus potassium. The results as summarized for recent experiments for Deschutes Valley sandy loam indicate that sulfur is having some effect on the liberation of potassium. This is also indicated by certain recent observations on Willamette silt loam. Composts with these soils have been prepared in the laboratory to test the effect of different rates of sulfur and gypsum on solubility of mineral plant food.

SULFUR FERTILIZERS ON VARIOUS SOIL TYPES

Sulfur fertilizer trials have been conducted on some two dozen of the leading soil types of Oregon, with results as summarized in Table XV. These trials indicate that at least 100,000 acres of alfalfa in Oregon

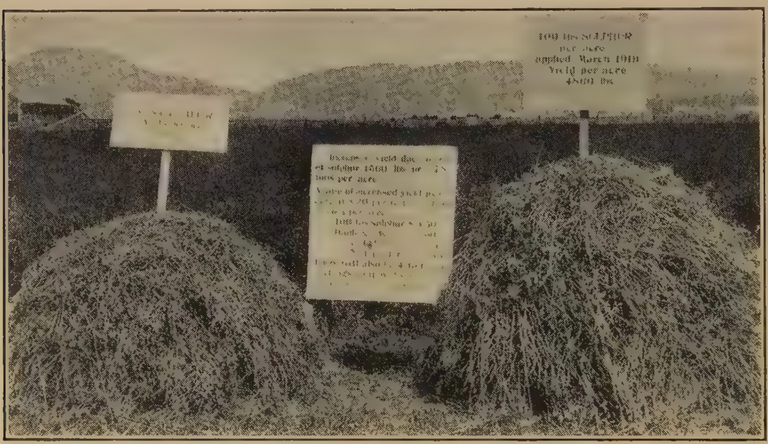

Fig. 9. Effect of sulfur on Klamath Project soil.

could be profitably sulfured. Another area of equal size which could be used for alfalfa in rotation should respond equally well. The soils responding range from fine sand to clay adobe. Some soils in the humid sections, notably the older grain lands in the lower Willamette Valley and the red hill lands, appear to be in need of sulfur in many cases.

Soils which do not respond to sulfur. A few soils have been found which do not appear to need sulfur. Medford loam and peat or muck soils, being well supplied with vegetable matter, contain a large sulfur supply. Medium and coarse sand in Umatilla basin receives nearly sufficient sulfur from the large applications of irrigation water applied and has given increases in but few cases. Willamette silty clay loam in the upper Willamette Valley contains 600 to 700 pounds of sulfur in an acre to plow depth, and since this sulfur oxidizes readily little increase is obtained from sulfur applications.

Correspondence with experiment stations and a study of station literature throughout the United States, and of rock composition, lead to the view that the basaltic soils of the Northwest offer the greatest field for profitable use of sulfur on soil in the United States.

TABLE XV. ALFALFA YIELDS WITH AND WITHOUT SULFUR ON VARIOUS SOILS OF OREGON

	Soil	Location and farm	No. of plots	Treatment Kind	Amt. per acre	Annual avg. yield per acre	Average gain from treatment
1	Antelope clay adobe	Bernst, Medford	10	None	--------	0.57	--------
			1	Gypsum	297.5	2.172	2.440
			4	Sulfur	100.0	2.678	2.108
2	Medford fine sandy loam	M. Hanley, Jacksonville	1	None	0.0	2.405	--------
			1	Gypsum	300.0	3.875	1.470
			1	Sulfur	300.0	3.460	1.055
3	Tolo loam	Frame, Talent, Oregon	2	None	0.0	1.142	--------
			1	Gypsum	590.0	1.908	0.766
			1	Sulfur	100.0	1.283	0.141
4	Phoenix clay adobe	Barneburg, Medford	2	None	0.0	1.549	--------
			1	Gypsum	595.0	3.552	2.002
			1	Sulfur	100.0	2.284	0.734
5	Medford gravelly clay loam	Hartley, Talent, Oregon	6	None	0.0	1.110	--------
			2	Sulfur	300.0	1.970	0.860
6	Salem clay loam	Hanley, Medford	3	None	0.0	1.305	--------
			1	Gypsum	595.0	3.654	2.349
			1	Sulfur	100.0	3.862	2.557
7	Coleman gravelly clay loam	Schnebley, Phoenix, Ore.	3	None	0.0	0.535	--------
			1	Gypsum	595.0	1.270	0.735
			1	Sulfur	100.0	1.090	0.555
8	Barron coarse sand	Schneider, Ashland	2	None	0.0	1.314	1.088
			1	Gypsum	374.0	2.401	--------
9	Salem fine sandy loam (coarser phase)	Modoc Orchard Table Rock	1	None	0.0	0.760	--------
			--	Gypsum	200.0	1.800	1.040
			--	Sulfur	200.0	1.530	0.770
10	Willamette silt clay loam	Ore. Exp. Sta. Corvallis	10	None	0.0	5.00	--------
			10	Sulfur	100.0	5.04	.04
11	Umatilla medium sand	Br. Exp. Sta. Supt. Dean	2	None	0.0	3.064	--------
			2	Sulfur	200.0	3.912	.848
			2	Gypsum	200.0	3.690	.626
12	Umatilla fine sand	Stanfield C. W. Connor	2	None	0.0	4.95	--------
			2	Sulfur	100.0	6.38	1.32
13	Fine sandy loam	Boardman Mr. Cobb	2	None	0.0	5.50	--------
			2	Sulfur	--------	6.25	0.75
14	Deschutes sandy loam	All exp. fields	8	None	0.0	3.00	--------
			10	Gypsum	60.0	4.73	1.73
			8	Sulfur	100.0	4.02	1.02
15	Very fine sandy loam	Dufur M. M. Burtner	2	None	0.0	1.50	--------
			2	Sulfur	100.0	4.00	2.5
16	Dark loam	Union Station Supt. Withycombe	8	None	0.0	6.43	--------
			2	Sulfur	--------	7.08	.625
			2	Gypsum	--------	7.24	.780
17	Dark loam	Carnes N. Powder	4	None	--------	2.50	--------
			4	Sulfur	100.0	4.00	1.50
18	Dark loam	Vale Russell	2	None	--------	2.29	--------
			2	Sulfur	100.0	2.41	.12
19	....	Harney Br. Sta. Supt. Shattuck	2	None	--------	4.91	--------
			2	Sulfur	100.0	5.10	.19
20	Sandy loam	J. F. Hansen Lakeview	6	None	--------	1.50	--------
			6	Sulfur	100.0	3.00	1.50
21	Klamath clay loam	Klamath Nelsons	5	None	--------	1.20	--------
			5	Sulfur	100.0	3.26	2.06
22	Yakima sandy loam	McClay Klamath	1	None	--------	3.30	--------
			1	Sulfur	100.0	4.86	1.56

Effect of sulfur on different crops (Table XVI). The yields of crops included in sulfur fertilizer trials is compiled in Table XVI. The legumes responding well to sulfur in order of increase are alfalfa and red and alsike clover. A number of crops of the legume and the cabbage

TABLE XVI. EFFECT OF SULFUR ON VARIOUS CROPS

Crop	Soil	Location and cooperator	Number of trials	Kind	Amt. per acre	Annual yield per acre	Gain from treatment
						(Tons unless indicated)	
Red clover	Agate gravelly sandy loam	Hilton, Medford	1	None	0	2.340	-------
			1	Gypsum	590	3,625	1.255
			1	Sulfur	100	4.740	2.400
Red clover	Agate gravelly loam	Rogue River	1	None	0	0.285	-------
			1	Gypsum	600	0.608	0.323
			----	Sulfur	105	0.825	0.540
Red clover	Willamette silty clay loam	O. A. C. Exp. Sta. Corvallis	7	None	0	4.855	-------
			7	Sulfur	320	6.500	1.645
Red clover seed	Carlton clay loam	Abraham No. Albany	3	None	0	197.0 lbs.	-------
			1	Sulfur	150	280.0 lbs.	83.0 lbs.
Red clover and timothy (manured)	Red hill	Astoria Br. Station Supt.	3	None	0	3.48	-------
			1	Sulfur	200	4.05	0.57 T
Alsike clover and timothy	Medium peat	Klamath F. McCormack	2	None	0	2.18	-------
			2	Sulfur	100	2.32	0.14 T
Field peas	Sandy loam	Klamath W. Johnston	----	None	0	3.92	-------
			----	Sulfur	200	3.92	0.00 T
Field peas	Very fine sandy loam	Harney Br. Exp. Station Supt. Shattuck	----	------------	------	5.50	-------
			----	------------	------	5.70	.20 T
Field peas	Antelope clay adobe	------------------------	----	------------	------	.90	-------
		------------------------	----	------------	------	1.00	.10 T
Peas and oats	Melbourne silty clay loam	Astoria Br. Exp. Station	3	None	------	2.00	-------
			1	Sulfur	200	2.325	.325 T
Peas and oats (silage)	Dark loam	Union Br. Exp. Station Supt. Withycombe	8	None	------	7.14	-------
			2	Sulfur	100	7.22	–.08 T
Field peas	Very fine sandy loam	Harney Branch Exp. Station	1	None	------	27.6 bu.	-------
			1	Sulfur	100	32.6 bu.	5.00 bu.
White beans	Dayton silty clay loam	Ore. Exp. Sta. Corvallis	4	None	------	11.0 bu.	-------
			1	Gypsum	100	1.0 bu.	0.0 bu.
Soy beans	Antelope clay adobe. Med soil	Exp. Field	----	None	------	816.0 lbs.	-------
			----	Sulfur	100	944.0 lbs.	128.0 lbs.
			----	Gypsum	250	1255.0 lbs.	439.0 lbs.
Oat hay	Powell silt loam	Corbett-Salzman	1	Manure	10 T	1.34	-------
			1	Sulfur and manure	100 lbs. and 10 T	1.57	.23
Oat hay	Willamette silty clay loam	State Exp. Sta. tanks Exp.	2	None	------	39 grams	-------
			2	Sulfur	100 lbs.	49 grams	10.0 grams
Oat hay	Deep peat	Lake Labish Tank Exp.	1	None	------	10.5 grams	-------
			1	Sulfur	100 lbs.	11.0 grams	.05 grams
Oats	Deschutes sandy loam	Becker—2 mi. N. Tumalo	1	None	------	25 bu.	-------
			----	Sulfur	80 lbs.	30 bu.	5.0 bu.

Oat hay	Deschutes sandy	Redmond	2	None	......	16.2	grams	43.7	grams
	loam	Tank Exp.	2	Sulfur	100	59.9	grams	....	
Barley	Antelope clay	Medford soil	1	None	......	13.5	bu.	....	
	adobe	Exp. Field	1	Sulfur	100	24.4	bu.	10.9	bu.
Barley	Deschutes sandy	Redmond	2	None	......	21.5	grams	....	
	loam	Tank Exp.	2	Sulfur	100	32.0	grams	10.5	grams
Barley	Willamette silty	O. A. C. Exp.	2	None	......	66.9	bu.	....	
	clay loam	Sta. Corvallis	2	Sulfur	320	60.9	bu.	-6.0	bu.
Barley	Newberg	Ore. Exp. Sta.	....	None	......	26.4	bu.	....	
	silt loam	Corvallis	....	Sulfur	160	28.7	bu.	2.3	bu.
Barley	Mellan very fine	Ontario	3	None	......	80.45	bu.	....	
	sandy loam	T. W. Claggett	2	Sulfur	100	81.50	bu.	1.05	bu.
Barley	Very fine sandy	Harney Br. Exp.	1	None	......	56.40	bu.	....	
	loam	Sta. Supt. Shattuck	1	Sulfur	100	69.10	bu.	12.7	bu.
Wheat	Willamette silty	O. A. C. Exp.	7	None	......	46.4	bu.	....	
	clay loam	Sta. Corvallis	2	Sulfur	320	51.2	bu.	4.8	bu.
Wheat	Carlton silty	Abraham	4	None	......	12.5	bu.	....	
	clay loam	No. of Albany	1	Sulfur	150	20.5	bu.	8.0	bu.
Wheat	Very fine sandy	Br. Exp. Sta. Moro	8	None	......	41.4	bu.	....	
	loam	Supt. Stevens	2	Sulfur	100	42.4	bu.	1.0	bu.
Wheat hay	Dark loam	E. Ore. Br. Exp. Sta.	4	None	......	2.27		....	
		Supt. Withycombe	1	Sulfur	100	2.36		.09	T
Wheat	Very fine	Harney Br. Exp. Sta.	2	None	......	63.60	bu.	....	
	sandy loam	Supt. Shattuck	1	Sulfur	100	58.40	bu.	–5.2	bu.
Corn	Willamette silty	O. A. C. Exp. Sta.	14	None	......	6.37		....	
	clay loam	Corvallis	4	Sulfur	320	6.80		.57	T
Corn	Newberg sandy	O. A. C. Exp. Sta.	42	None	......	4.69		....	
	loam	Corvallis	6	Sulfur	320	4.16		–.53	T
Corn	Olympic silt	Shaw	4	None	......	7.20		....	
	loam	C. J. Gilbert	1	Sulfur	100	9.40		2.20	T
Corn	Powell silt loam	Corbett-	2	None	......	11.05		....	
		Salzman	1	Sulfur	100	11.99		.94	T
Corn	Dark loam	E. Ore. Ex. Sta.	4	None	......	10.50		....	
		....	1	Sulfur	100	12.00		1.50	T
Corn	Malheur, very	Ontario	....	....	......	....		....	
	fine sandy loam	T. W. Claggett	....	....	......	....		....	
Potatoes	Yakima	Klamath Proj.	1	None	......	250.0	bu.	....	
	sandy loam	S. E. Heseltine	1	Sulfur	100	249.3	bu.	–.3	
Potatoes	Deschutes sandy	Redmond Exp.	7	None	......	107.4	bu.	....	
	loam	Sta. C. A. Adams *et al.*	2	Sulfur	100	125.4	bu.	18.0	
Potatoes	Powell silt loam	Corbett-	2	None	......	181.5	bu.	....	
		Salzman	1	Sulfur	100	235.8	bu.	54.3	
Beets	Very fine	Harney Br. Exp.	2	None	......	5.8		....	
	sandy loam	Sta. Supt Shattuck	2	Sulfur	100	5.5		–.3	T
Kale	Willamette silty	Ore. Exp. Sta.	7	None	......	13.1		....	
	clay loam	Corvallis	2	Sulfur	320	15.8		2.7	T

families were included in a trial in 1920 and 1921 to test the effect of sulfur and gypsum when grown on antelope clay adobe. The effect of sulfur on field peas, so far as tried, is not striking. On antelope clay adobe soy-beans yielded 816 pounds an acre unfertilized in 1920. With one hundred pounds of sulfur an acre the yield was 944 pounds, and with 250 pounds of gypsum an acre the yield was 1255 pounds.

Among the cereals, oats required most sulfur. Some moderate increases have been secured from sulfur with wheat and corn. Sulfur applied to kale and rape on Willamette silty clay loam at Corvallis in 1913 failed to give an increase in yield. Kale and sunflowers fail to respond to sulfur.

TABLE XVII. 1921 SERIES. INOCULATED SULFUR VS. UNINOCULATED SULFUR

Antelope clay adobe, Southern Oregon Soil Experiment Field. Seeded 1920. Treated July 14, 1921. Yield pounds per acre.

Plot		1921 Last cutting	1922 First cutting	1922 Second cutting	Tons for yr.
1	Check	1215	2830	1180	2.065
2	100 pounds to the acre Inoculated sulfur	1215	3410	1540	2.475
3	100 pounds to the acre Sulfur	1115	3735	1540	2.135
4	Check	1180	3035	1425	2.230

TABLE XVIII-A. VALUE OF SULFUR IN CONNECTION WITH MANURE AND ROCK PHOSPHATE

1920 Series: Oregon Experiment Station, Soil Experiment Field, Medford.

Plot	Treatment: Fertilizer	Treatment: Amount per acre	Cost	Yield per acre —Average for 2 years—1920, 1922— tons	Incr. S.		Net
	Manure	20 T	——	——	——	——	——
1	Sulfur	100 lbs.	$2.00	2.31	1.055	$10.55	9.55
	Manure	20 T	——	——	——	——	——
	Sulfur	100 lbs.	2.00	——	——	——	——
2	Rock phosphate	281 lbs.	2.81	2.225	.970	9.70	7.30
3	Manure	20 T	——	1.255	——	——	——
4	Check	0	——	.565	——	——	——

Treatments applied September, 1920.

TABLE XVIII-B. VALUE OF SULFUR IN MAKING PHOSPHORUS AVAILABLE

Cascade silt loam (hill phase) Multnomah county.

Treatment Kind and rate per acre	Yield per acre tons: Corn 1920	Potatoes 1921	October hay—1922: No lime	October hay—1922: Limed 1½ tons an acre
Untreated check plots, average	11.047	5.445	.975	1.263
Sulfur 100 lbs.	11.987	7.074	.957	.891
Manure 10 tons	11.918	5.895	1.343	1.436
Sulfur + manure 10 tons	12.946	8.910	1.569	1.584
Superphosphate 250 lbs.	12.591	6.525	1.091	1.197
Rock phosphate 500 lbs.	11.613	5.670	.9609	1.157
Sulfur 100 lbs. + rock phosphate 500 lbs.	——	——	.944	1.277
Sulfur 100 lbs. + rock phosphate 500 lbs. + manure 10 tons	——	——	1.197	1.569

Value of activated or inoculated sulfur (Table XVII). Practically all the striking results obtained from sulfur as a fertilizer in Oregon have been secured with uninoculated ground sulfur. The bacteriologists of the Oregon Station find that many Oregon soils contain a plentiful supply of sulfofying bacteria, and that sulfur oxidizes at a more rapid rate than required by crops. Under severe or unfavorable climatic or soil conditions it is necessary to apply sulfur several weeks before growth begins, and it is generally helpful to harrow it in, or use some gypsum the first season with late applications.

In the spring of 1921 a supply of activated sulfur was secured through the courtesy of Dr. Jacob Lipman, director of the New Jersey Experiment Station, for use in field trials at Medford and Hermiston. Further trials have since been added at the branch station at Union, Oregon. No definite response from sulfur was obtained at Hermiston

Fig. 10. Effect of sulfur, Deschutes Valley trials.

Station even when used with manure or activated, until the present year, when the spring rain lessened the amount of early irrigation. At Medford some advantage was gained in point of time by use of inoculated sulfur.

VALUE OF SULFUR AND SULFATES IN RESTORING STRUCTURE OF DRAINED ALKALI LAND

Many years ago Dr. Hilgard[23] suggested the application of calcium sulfate or gypsum to black alkali for converting it into soluble form in the soil so that it could be "laundered" out following drainage by copious irrigation. Dr. Scofield[24] more recently has proposed the use of aluminum sulfate to prevent the running together of land containing black alkali, and has suggested that this running together is due to the action of soda salts on the silicate in the soil, causing the development of colloidal sodium silicate, or water-glass. Aluminum being trivalent, rapidly setting free the sulfuric acid in the soil, is looked to by him as a

permanent corrective for breaking up or overcoming this colloidal condition. Some interesting results with sulfuric acid were obtained by Dr. Lipman[8] in California experiments.

In 1918 and 1919 sulfur applications were used on sweet clover seedings on land affected with alkali near Klamath and Ontario. There was an improved growth of sweet clover, which was calculated to add green manure and loosen the soil. There was apparently an improvement in the structure of the land, which was given copious irrigation.

Improvement of alkali land is regarded as one of the larger soil problems in Eastern Oregon, and has been made the object of special investigation during the past three seasons. Experiments outlined by the writer and placed in charge of W. W. Johnston of the Soils department will be reported in detail later. Since good progress has been made, these experiments are here briefly referred to.

Fig. 11. Effect of sulfate on clover nitrification.
1 Untreated. 2 Lime. 3 Lime and sulfur. 4 Sulfur.

A ten-acre tract was selected near Vale at the beginning of the season 1921, having a mixed growth of sagebrush and greasewood, being situated within reach of an outlet into the river channel. A ditch was started with the use of a V-grader, Fresno scraper. A stream of water amounting to 4 or 5 cubic feet a second was then run through, while the soil was scarified by means of a one-horse cultivator. This sluicing method proved to be an economical method of building ditches, and a local farmer, Mr. Purvis, perfected a scarifying tool similar to a thresher cylinder to facilitate this process.

The experimental tract was then cleared and checked for irrigation and sampled. It was divided into some twenty half-acre plots, treated with different amounts of sulfur, gypsum, gypsum and manure, and aluminum sulfate. Straw cover and sweet clover straw containing matured seed were also employed. The land was given copious irrigation the first season, amounting to a total depth of 48 to 60 inches. A large proportion of the soluble white alkali was removed during this first season's flushing, as indicated by determinations at the end of the

season. Sweet clover and rye were planted and a spotted crop secured the following summer. The amount of black alkali was not substantially reduced, and except with the heavy sulfate treatments, it largely remained in the land, while on an average more than a ton an acre of total salts was washed out of the land.

Flushing was continued through the second season. Percolation was found to proceed better, particularly on treated plots due to improved structure. A large part of the black alkali was removed where sulfates were applied. This soil is well supplied with calcium. Rye and sweet clover were again seeded, and where the best treatments have been employed a fair crop is being secured.

Fig. 12. Purvis sluicing machine.

The bearing strength of bricks made of this soil in the laboratory, sun dried and tested in the engineering laboratory, have been found to be reduced about one-half with certain sulfate treatments, particularly heavy applications of gypsum and manure.

The seeding of ditched, uncleared land appears to be advantageous during the flushing process, and some native and volunteer growths offer opportunity for pasture during reclamation, thus reducing expense. Eight dollars' worth of sulfur made possible a ton of rye an acre where nothing grew before. Field work is checked by tank work in the greenhouse where rye and sweet clover have been grown with fair success on tanks given sulfate treatment, a maximum growth occurring on tracts receiving heavy application of alum, sulfur, gypsum, or manure. The leaching process in the field has removed a quarter to a third of the nitrate and sulfate content of this soil. Trials with ammonium sulfate and other applications for replenishing fertility are under way. Detailed data will be the subject of another report.

Value of sulfur in aiding solubility of phosphorus (Table XVIII). Sulfur rock-phosphate composts have been studied by Lipman[26] and

others for making phosphate available. Field trials have been conducted in recent years to test out the practicability of applying sulfur and ground raw rock phosphate for maintaining supply of these elements in certain Oregon soils. Two of the experiments for which there is more than one year's record are reported in Table XVIII.

Experiments started on antelope clay adobe in the spring of 1919 (Table XVIII-a) were planned to test the value of sulfur and manure in making available phosphorus in raw rock phosphate. The experiment gives indication that the treatment will prove economical. The soil is giving marked response to barnyard manure.

In experiments on the Carlton silty clay loam in Benton county (Table XVIII-b) and Cascade Powell silt loam in Multnomah county

Fig. 13. Ditch made with Purvis sluicer.

in the humid sections, sulfur, rock phosphate, manure, and lime have given some of the largest yields. Lime, however, was added at another time in the rotation than was the sulfur.

Composts prepared by Professor C. V. Ruzek to study liberation of phosphate in red hill soils were made to include sulfur at the suggestion of the writer. These studies will be a subject for a separate report. The effect of sulfur in this study is briefly summarized by Professor Ruzek as follows:

"Sulfur, and sulfur and manure, composted with rock phosphate and soil increased the amount of available phosphorus. These composts showed a gradual increase during the first twelve weeks of incubation, and then gradually decreased. Clover grown in pots in the greenhouse showed a more marked gain in yield than indicated by analyses. When

lime was added to these mixtures it retarded the availability of the rock phosphate."

Value of sulfur and sulfate alternated with ground limestone in humid climates. Trials are under way including the sulfur, lime, and manure combinations, especially on four humid red hill soils (Table XIX). Sulfur has given slightly greater increases than phosphorus on these soils, and lime has given moderate to good results. In the Multnomah experiment just cited, lime, manure, and sulfur have given good results on a soil containing good amounts of phosphorus but of rather low availability, due to high iron content. Sulfur alone has depressed growth of vetch in one instance. Sulfur alone applied to Willamette silty clay loam at Corvallis has increased acidity somewhat. In the Multnomah county experiment above cited, combined application of sulfur and manure gave the highest yields.

The yield of spring wheat on Carlton silty clay loam in Benton county, 1922, for plots involving sulfur is reported in Table XIX.

TABLE XIX-a. USE OF SULFUR IN ALTERNATION WITH LIME FOR HUMID SOILS—CARLTON SILTY CLAY LOAM, BENTON COUNTY

Treatment	No lime	Lime, 2 tons an acre
Ave. all checks. Wheat, bushels per acre	12.6	12.5
Sulfur 150 pounds an acre	31.7	20.5
Sulfur 150 pounds an acre and manure 10 tons + rock phosphate 1000 pounds an acre	19.5	15.0
10 tons manure and treble superphosphate 110 pounds an acre	14.5	12.7

A dry season caused lower elevations to yield more and interfered.

In Marion county in a fertilizer experiment on Olympic clay loam that had been limed and manured the yields were as follows:

TABLE XIX-b. USE OF SULFUR ALTERNATED WITH LIME OLYMPIC SILTY CLAY LOAM, MARION COUNTY

	Corn yield in tons
Lime 2 tons and manure 10 tons an acre	7.20
Lime 2 tons and manure + sulfur 100 pounds an acre	9.40
Lime 2 tons and manure + sulfur + rock phosphate 600 pounds an acre	11.00
Lime 2 tons and manure + rock phosphate	6.28
Lime 2 tons and manure + treble superphosphate 100 pounds	8.00
Lime 2 tons and manure + acid phosphate 250 pounds	8.86

Here the sulfur and rock phosphate on limed, manured land gave the maximum yield. This experiment is of too short duration to warrant any definite conclusion as to value of sulfur on these soils.

EFFECT OF SULFUR ON ACIDITY OF HUMID SOILS

Heavy and repeated applications of sulfur have been made in the Oregon experiments to learn the ultimate effect of using sulfur upon soils. Samples of the oldest (1915) series of plots on antelope clay adobe were collected (1922) and submitted to the Truog acidity test. Only slightest acidity was found in the case of the one plot receiving 600 pounds an acre of sulfur at each application. These samples were also

submitted to the department of Bacteriology for hydrogen-ion tests with results as follows:

TABLE XX. EFFECT OF SULFUR ON REACTION

	Can	Plot. No.	Treatment	Amount 1915-'17-'20	Ph. *
1915	1	5	Check		7.2
1915	2	6 E	Sulfur	100 pounds an acre	7.0
1915	3	7 W	Sulfur	300	7.0
1915	4	7 E	Sulfur	300 reapplied	7.0
Jan. 1916	5	2	Sulfur	600	6.8

* Ph. 7.0 represents neutrality, lower values acidity.

Samples were collected in November, 1922 from certain of the fertility plots on Willamette silty clay loam started at Corvallis in 1914 and retreated in 1917 and 1920 at rates given in Table XXI. Tests were made by the department of Bacteriology with results as follows:

TABLE XXI. EFFECT OF VARIOUS FERTILIZERS ON H-ION CONCENTRATION

Plot	Treatment	Sample A	Sample B
13	Check	5.7	5.7
14	Nitrate 100 pounds	5.8	5.8
15	Potash sulfate 160 pounds	5.7	5.8
16	Superphosphate 320 pounds	5.6	5.6
17	Check	6.0	5.8
18	3000 hydrated lime	6.8	6.4
19	320 pounds sulfur	5.4	5.3
20	Manure 12 tons	6.3	6.2
21	Check	5.8	6.0
22	Potash, Nitrogen and Phosphate	5.8	6.0

The figures represent the Ph. values. Ph. 7.0 represents neutrality, lower values acidity.

Professor W. V. Halversen, who made these tests, makes the following observation:

"There are three very interesting things brought out by these tests; namely, (1) the neutralizing value of both lime and manure, (2) the acidity produced through the oxidation of sulfur, and (3) the fact that superphosphate has had very little effect on the reaction of the soil."

Some humid soils which are deficient in sulfur and respond to applications may not require repeated treatments, or the treatments may be lighter after the initial application. Continued use of sulfur on such humid soils may make more necessary occasional liming, alternated with sulfur applications.

EFFECT OF SULFUR ON NITRIFICATION

The dark green color of sulfured alfalfa, the increased nodule formation and higher protein content in irrigated sections all indicate that there is an important relation between sulfur and nitrification. This may be very different in an arid soil of alkaline reaction from what exists in a humid soil of moderate acidity. Use of gypsum on clover in Western Oregon is an established practice and has been followed for a generation. Gypsum is used on the Experiment Station farm as a definite aid in establishing a new seeding of clover. To study the effect of such treatments the writer ran some pot tests with Dayton silty clay loam in March, 1921. The soil was brought in from the field at the close of the rainy season in quantity sufficient to fill 8 one-gallon earthenware jars. Four jars were planted to red clover and four were kept as a fallow series. One pot of each series was treated with sulfur, a second pair with gypsum, and a third with sulfur and lime. The remaining pair were used as controls. Jars were kept at about the optimum moisture content under greenhouse conditions and sampled and tested for nitrate every

Fig. 14. Plots used in alkali reclamation experiments.

ten days. At the beginning of the trial scarcely a trace of nitrate could be found in the soil used. Nitrates began to form during the first ten days, and differences increased until the harvest time in June, when results were as reported in the following table:

DAYTON SILTY CLAY LOAM, SPRING 1921

	Treatment	Mgs. NO_3 per 100 gms. soil	Yield of clover in grams per pot	Yield of clover in grams per pot
Clover		Fallow pots	Clover pots	
1	None	57.1	21.0	11.51
2	100 pounds an acre sulfur	33.6	12.4	12.94
3	100 pounds sulfur + 3000 pounds lime	49.8	25.1	12.38
4	200 pounds gypsum	43.0	9.2	8.95

This trial indicated that with this acid soil sulfur alone tended to depress nitrification, while its use in combination with lime stimulated nitrification.

This led to a more careful study of the problem by the department of Bacteriology with a humid soil known to respond to sulfur, with results described by Professor W. V. Halversen as follows:

"It is generally conceded that alfalfa and clover are heavy nitrate feeders. At the same time it will be readily surmised that nitrate production would be inhibited through the accumulation of inorganic acids. These lines of reasoning would lead us to conclude that the phenomenal increase in the yield of alfalfa when sulfur is applied to some soil types is entirely due to the supplying of a limiting plant food element.

"To check carefully on the relation of sulfur oxidation to nitrate production, some tests and observations were made on a sample of Carlton clay loam. A large sample was procured from the field, divided into

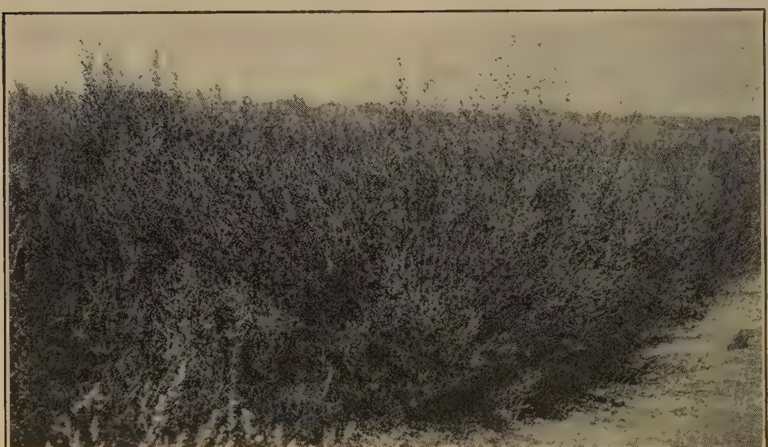

Fig. 15. Sweet clover on partly reclaimed alkali land.

seven portions, and treated as shown in the following table. Each of these portions was again divided and placed in two gallon jars in the greenhouse, one portion being kept fallow and the other planted to clover.

"The following table shows an intimate relationship to exist between the soil treatment, nitrifying power, and crop yields.

No.	Treatment	Mgs. N.as NO_3 per 100 gms. soil Fallow (4 det.)	Yield of clover in grams per pot	H-ion concen-tion
1	Check	4.50	13.9	5.8
2	100 pounds sulfur	3.95	16.3	5.7
3	500 pounds sulfur	3.92	12.9	5.5
4	200 pounds gypsum	4.12	15.7	5.8
5	100 pounds sulfur + 2000 pounds lime	5.83	16.6	6.0
6	500 pounds sulfur + 200 pounds lime	5.05	15.5	5.7
7	2000 pounds lime	5.29	15.0	6.0

"Determinations have been made on the amount of nitrate accumulating in the soil and also on the power of the bacteria in the soil to pro-

duce nitrates from ammonia. Though this work is still in progress certain things seem apparent.

Fig. 16. Greasewood land, Vale, Oregon. Rye failed after drainage and with no chemical treatment.

Fig. 17. Greasewood land, Vale, Oregon. Received sulfur and manure and yielded one ton of rye hay an acre after drainage and flushing.

"1. That the application of sulfur alone lowers the nitrate producing power, whereas 100 pounds of sulfur applied with one ton of lime stimulates the nitrate producing power of Carlton clay loam.

"2. Lime and sulfur together gave the largest yield of clover under greenhouse conditions. The second largest yield of clover came from 100 pounds of sulfur alone per acre.

"3. The oxidation of large quantities of sulfur materially lowers the yield of clover, also the nitrate-producing power and increases the acidity of this soil type.

"This problem is being carried out in the Bacteriology department in cooperation with the Soils department."

EFFECT OF SULFUR ON WATER REQUIREMENT

Sulfur treatments included in tank and pot water-requirement studies indicate that sulfur is an especially critical element, although only a little seems to be required. Results of one such trial are given as an illustration.

WATER REQUIREMENT OF OATS GROWN ON DESCHUTES MEDIUM SANDY LOAM SOIL

	Yield	Water requirement per lb. dry matter
Untreated	16.2 gm.	2125 pounds
Sulfur 100 pounds an acre	57.9 gm.	594 pounds

VARIOUS EFFECTS OF SULFUR IN AGRICULTURE

Sulfur controls many plant diseases and parasites. Potato scab is held to be decreased by sulfur as a result of increased soil acidity, and activated sulfur is regarded by the New Jersey Station as more prompt and effective for this purpose than ordinary sulfur. The red spider pest has been effectively controlled by dusting with sulfur on Oregon soil plots. Eel worm and numerous other pests are controlled with sulfur. Sulfur is used in numerous ways and applied in stables may prevent spread of some diseases in manure.

RECOMMENDATIONS AS TO USE OF SULFUR ON OREGON SOILS

Sulfur is essential to crops, especially legume crops and those of the cabbage family, many of which require more sulfur than phosphorus.

Sulfur appears to be insufficient in soil to insure good crops, especially in the arid and semi-arid sections or the old leached, basaltic hill lands in the more humid sections of Oregon.

Application of eighty to one hundred pounds of sulfur an acre every three or four years should give a ton or more increase in yield of legume hay on most of the alfalfa lands of the state. Subsequent applications may be lighter, especially on humid soils. Apply early and harrow in at the time meadows are renovated. Fall application is best under dry farming or where sulfur is slow acting, for this material must oxidize to sulfate form to become available.

The method of applying sulfur may be the same as with land-plaster. Mixing damp sand with equal parts of sulfur will lessen drifting and render sulfur less obnoxious to broadcast by hand.

Ground commercial sulfur should best overcome any sulfur deficiency in soils over a period of years.

Where sulfur is deficient in humid sections of Oregon ground commercial sulfur judiciously employed will often be cheaper treatment than gypsum for legumes.

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